New Empirically-Derived Solar Radiation Pressure Model for GPS Satellites

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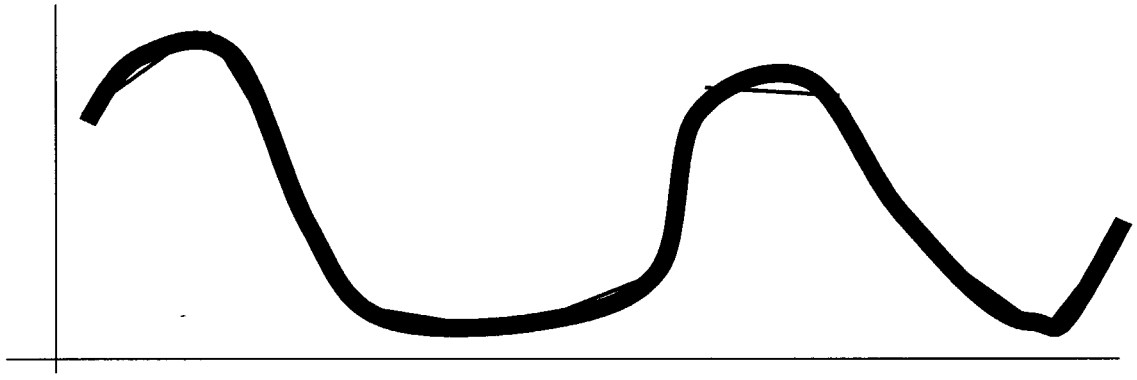
Outline

- GPS SRP model development strategy
    - orbit data
    - model parameterization

- GPS SRP model parameters improvement
    - improvement for orbit fitting
    - improvement for orbit prediction
    - parameter characteristics

- Possible physical causes of the parameters
    - sampling effect of orbital arc
    - mismodeling of satellite attitude
- Summary

Strategy



- Using daily FLINN solution as truth orbit

- Fit the truth orbit over long orbit arc with purely dynamical model (10 day orbit fitting)

- Combining all fitting solution into Block IIA and Block IIR model parameters

- Assess the model quality with prediction test

GPS Orbit Data

- Daily FLINN orbit solution with 15 minute interval

- ECEF solution converted to ECI using IERS Bulletin-B EOP values

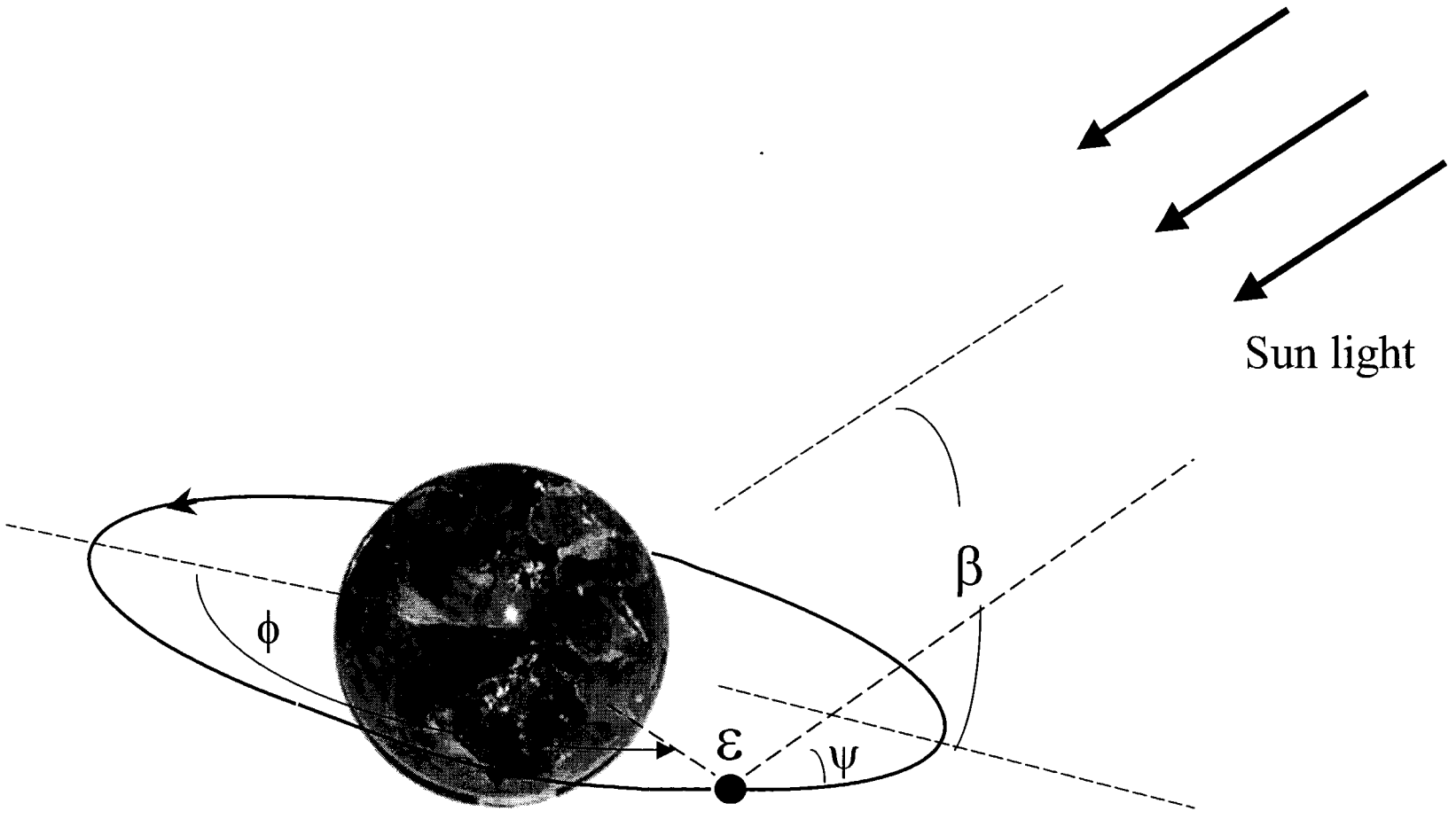
- Consecutive 10 days with 3D overlap RMS < 20 cm

- Covering Jan 1, 1998 through Jul, 7, 2002,

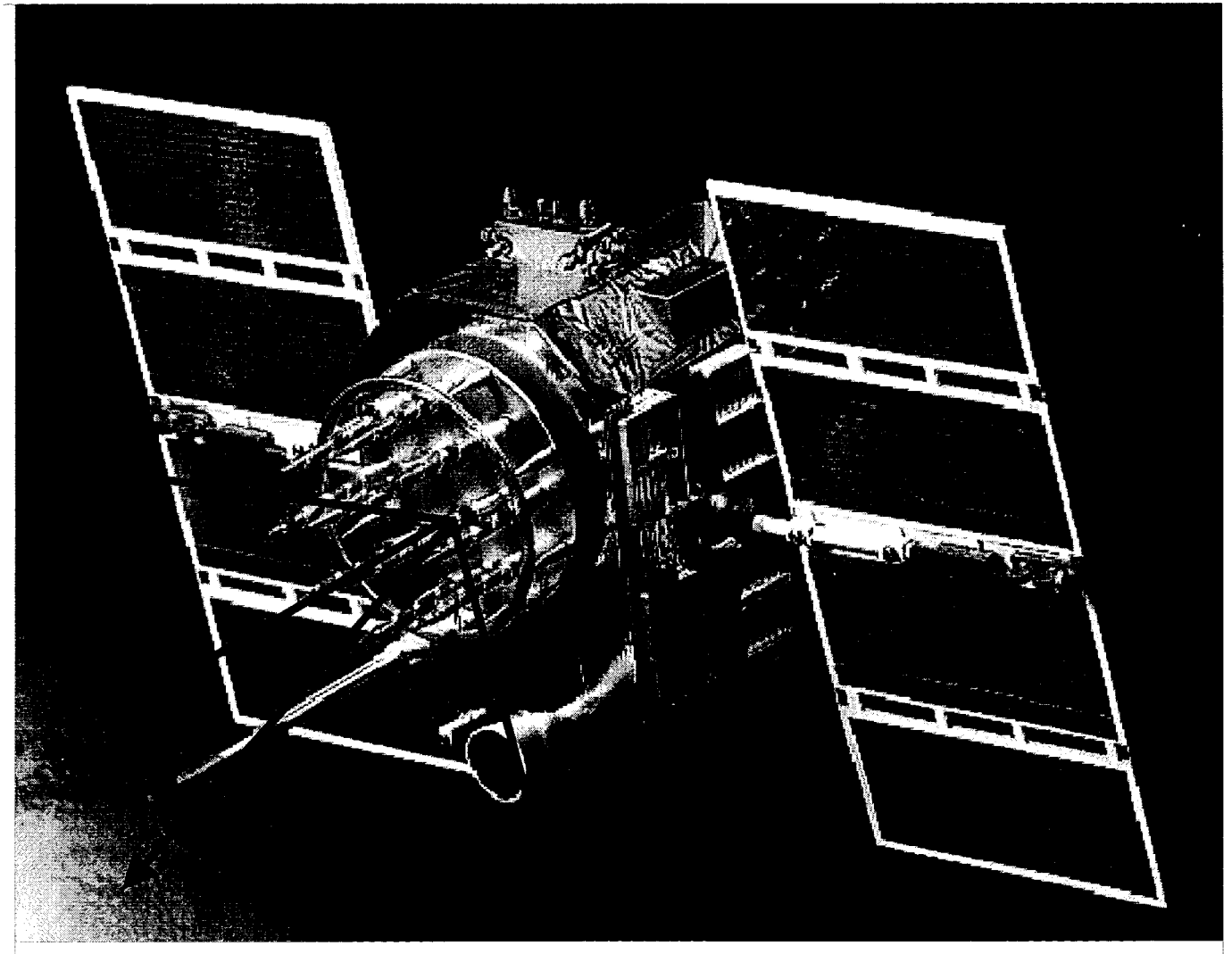
- 15 Block IIA satellites, 6 Block IIR satellites

- 1500 noneclipsing arcs, 540 eclipsing arcs

Earth-Probe-Sun Geometry



Attitude and Coordinate System



Model Parameters

Fourier Expansion of Force Function

$$Fu = C_U(0) + C_U(1) \cos \varepsilon + S_U(1) \sin \varepsilon + C_U(2) \cos 2\varepsilon + S_U(2) \sin 2\varepsilon + \ldots$$

$$Fv = C_V(0) + C_V(1) \cos \varepsilon + S_V(1) \sin \varepsilon + C_V(2) \cos 2\varepsilon + S_V(2) \sin 2\varepsilon + \ldots$$

$$Fw = C_W(0) + C_W(1) \cos \varepsilon + S_W(1) \sin \varepsilon + C_W(2) \cos 2\varepsilon + S_W(2) \sin 2\varepsilon + \ldots$$

Combining Arc Solutions

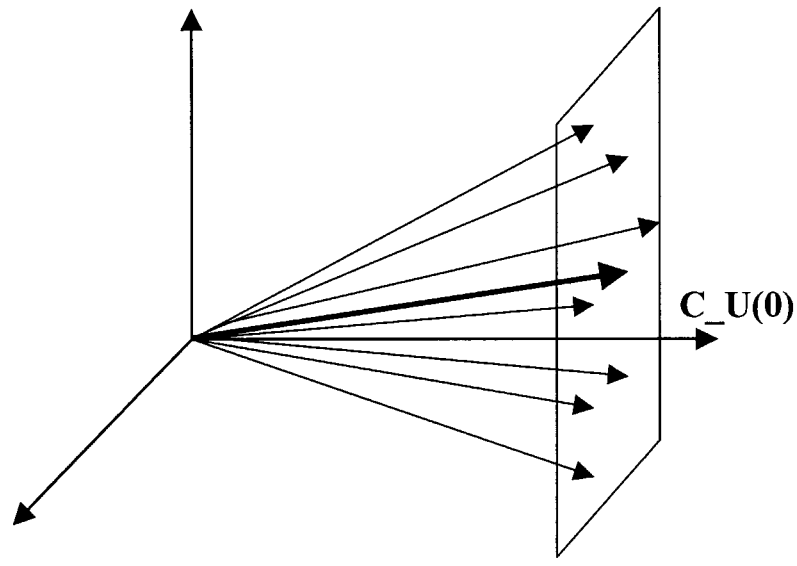
- Arc solutions are combined into Block IIA and Block IIR Models

- Find the weighted mean of the main force term, C_U(0)

- Scale each solution to the mean C_U(0)

- Find the weighted mean of other components of the scaled solution vectors

- the C_V(1) term is represented with a function of β



Combined Solutions

Parameters for Block IIA

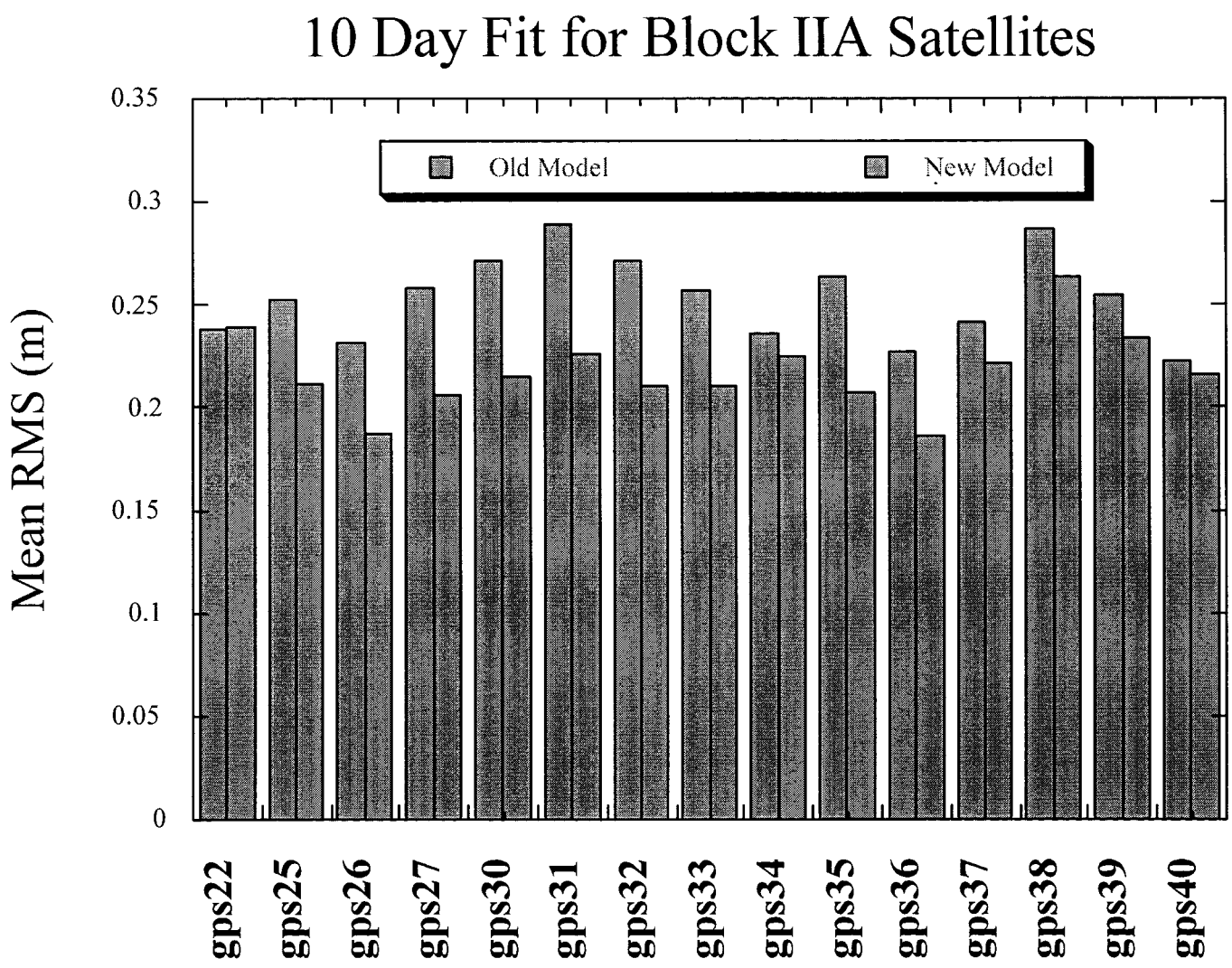
C_U(0) = 8.881 10^{-5} Newton
C_U(1) = 0.067
S_U(2) =-0.008
C_W(1) =-0.120
S_W(1) = 0.011
C_W(2) = 0.036
C_V(2) = 0.188 10^{-9} m/sec^2
C_V(1) = 0.083
+ 0.556 Sin β
+ 0.273 /Sin β

Parameters for Block IIR

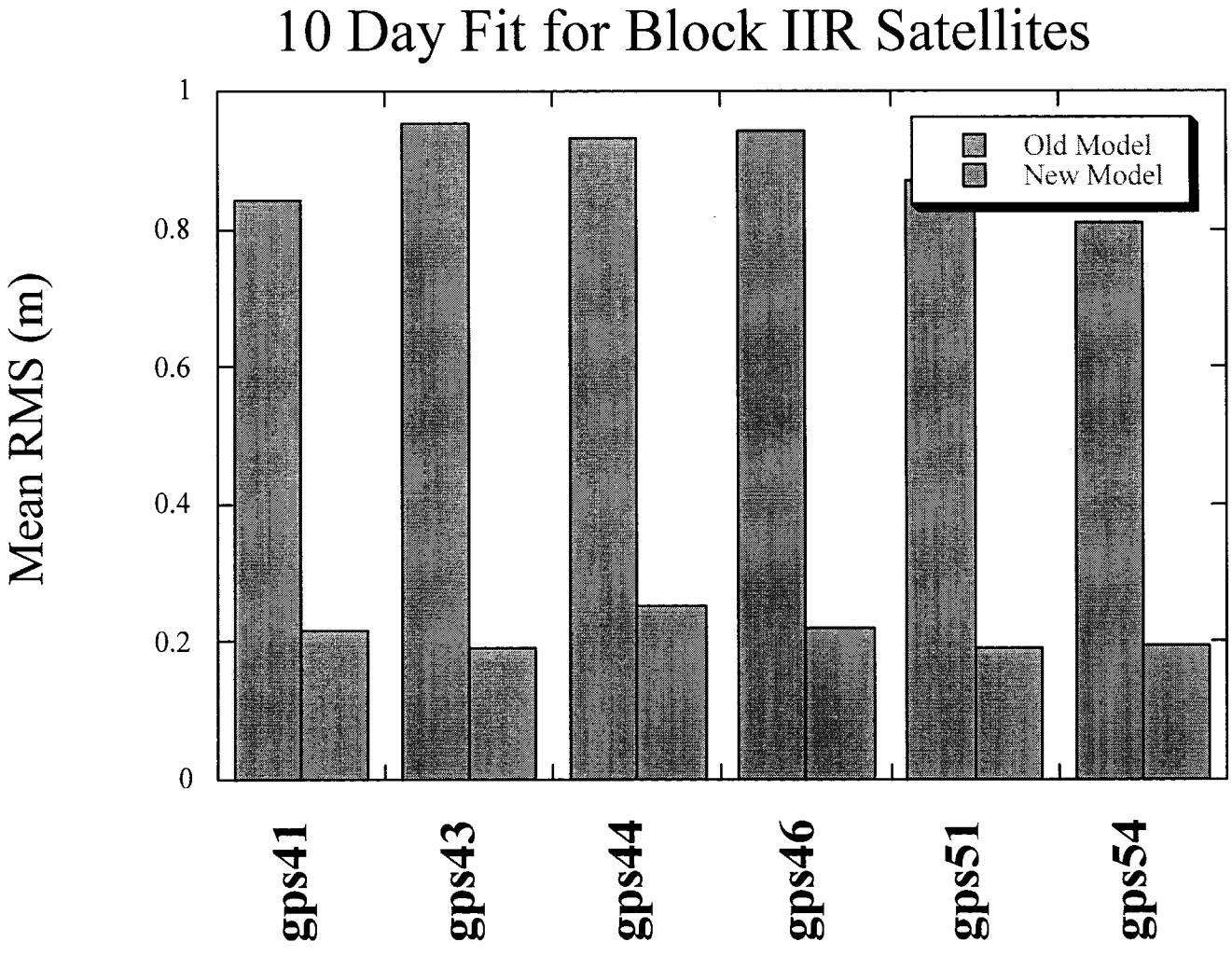
C_U(0) = 11.190 10^{-5} Newton
C_U(1) = 0.553
S_U(2) =-0.243
C_W(1) =-0.167
S_W(1) =-0.060
C_W(2) = 0.025
C_V(2) = 0.061 10^{-9} m/sec^2
C_V(1) = -0.008
+ 0.181 Sin β
+ 0.097 /Sin β

The combined model will have a scale factor and Y-bias term to be determined

Improvement on Data Fit

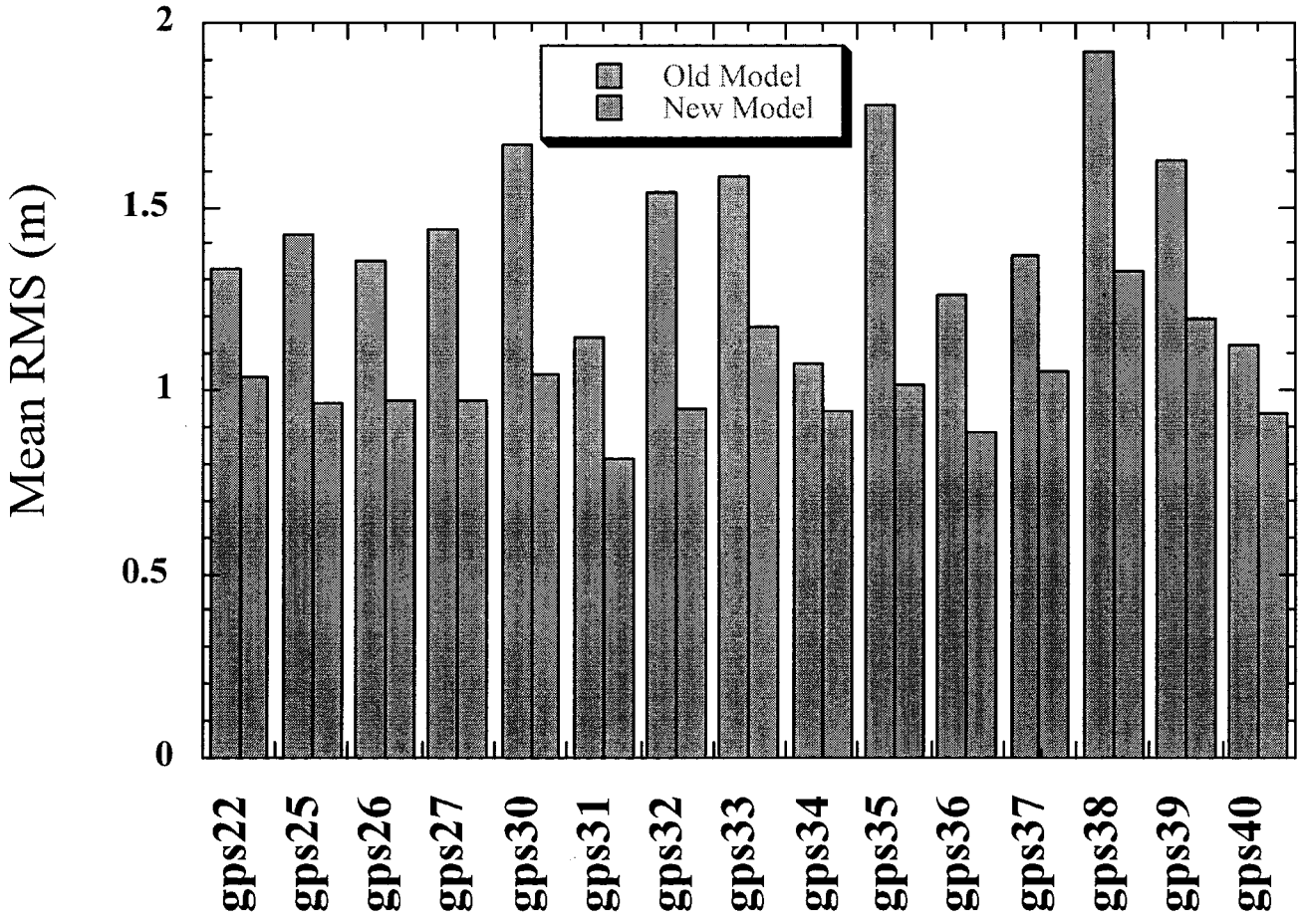


Improvement on Data Fit



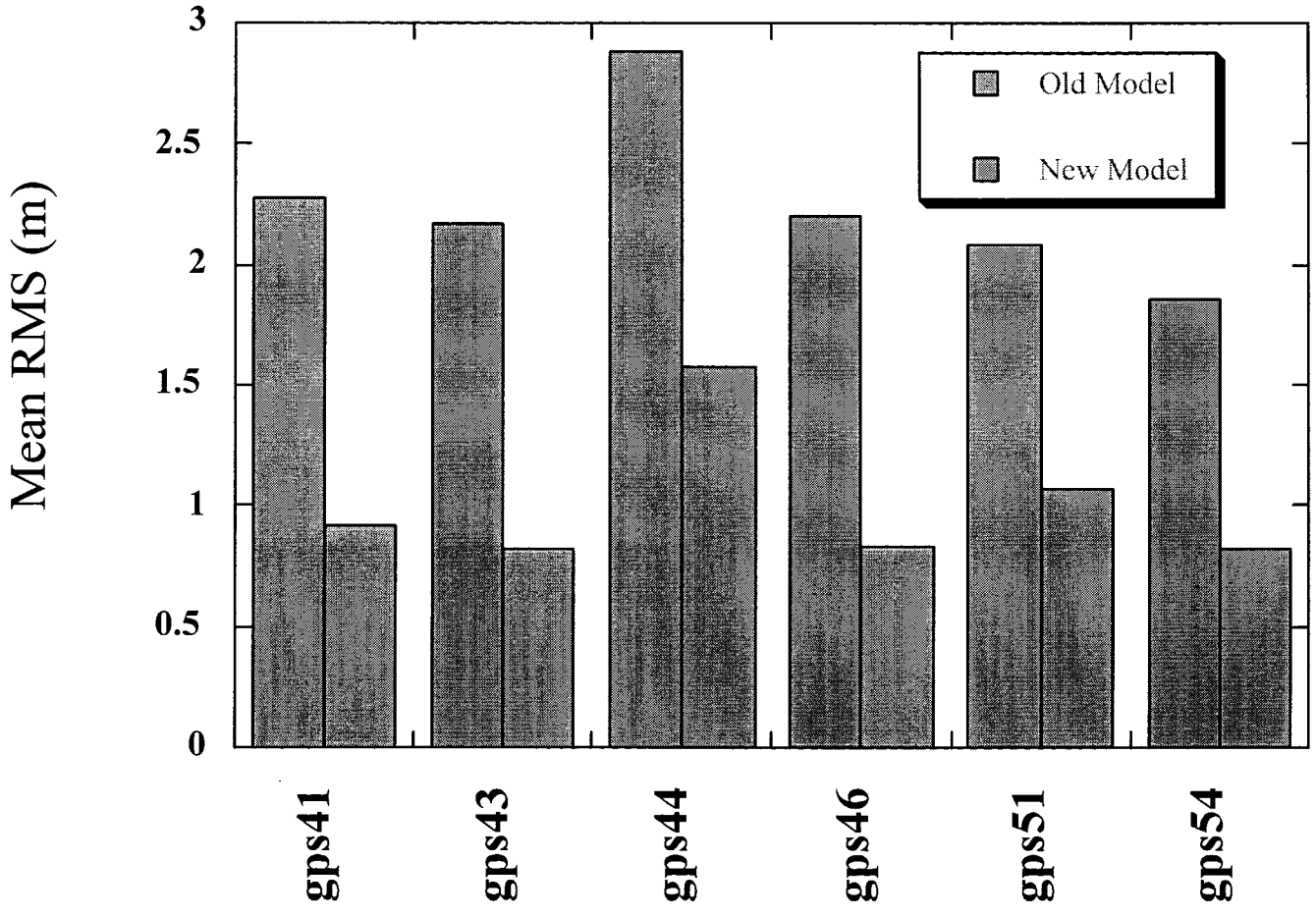
Improvement on Orbit Prediction

4 Day Prediction for Block IIA Satellites

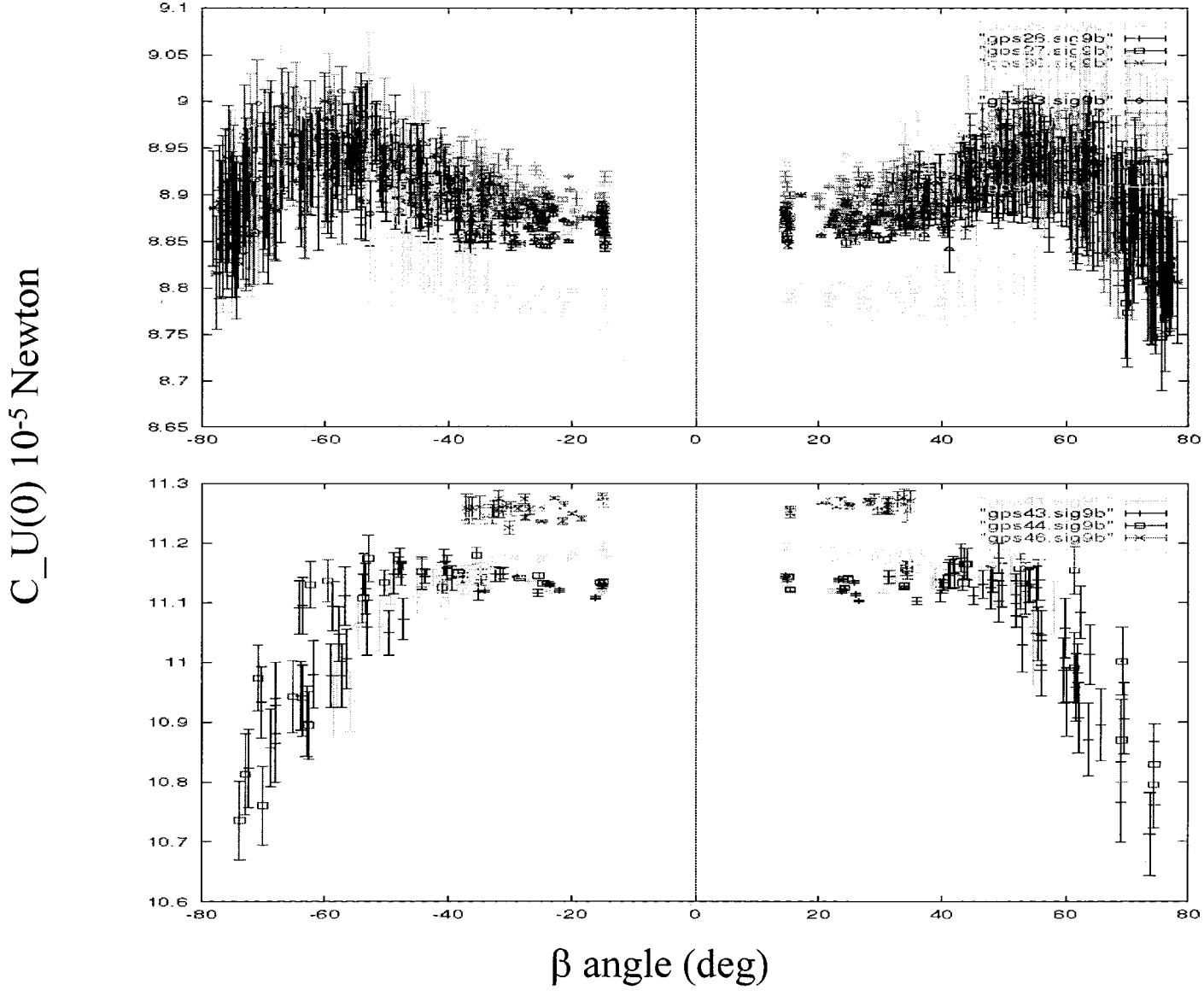


Improvement on Orbit Prediction

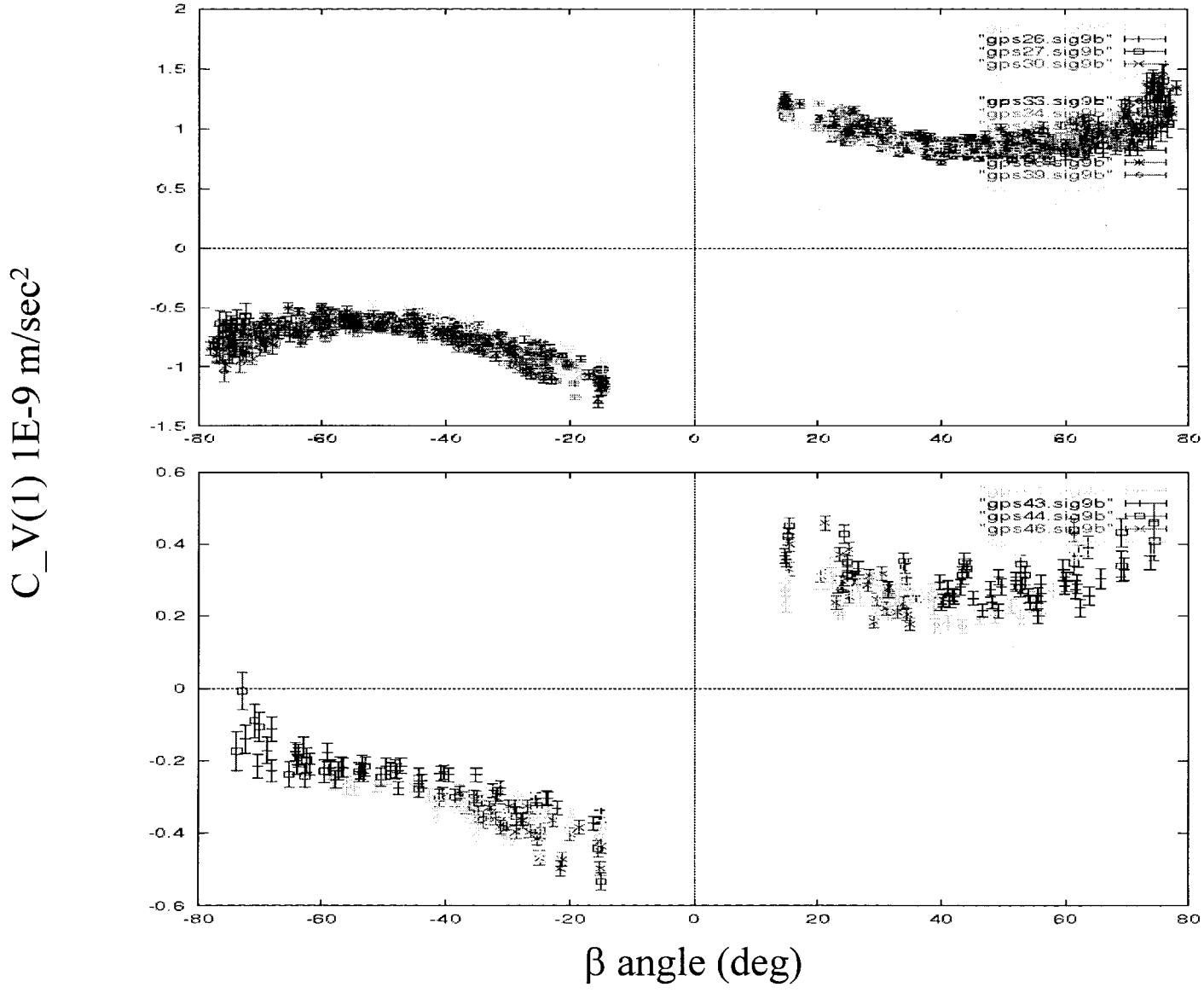
4 Day Prediction for Block IIR Satellites



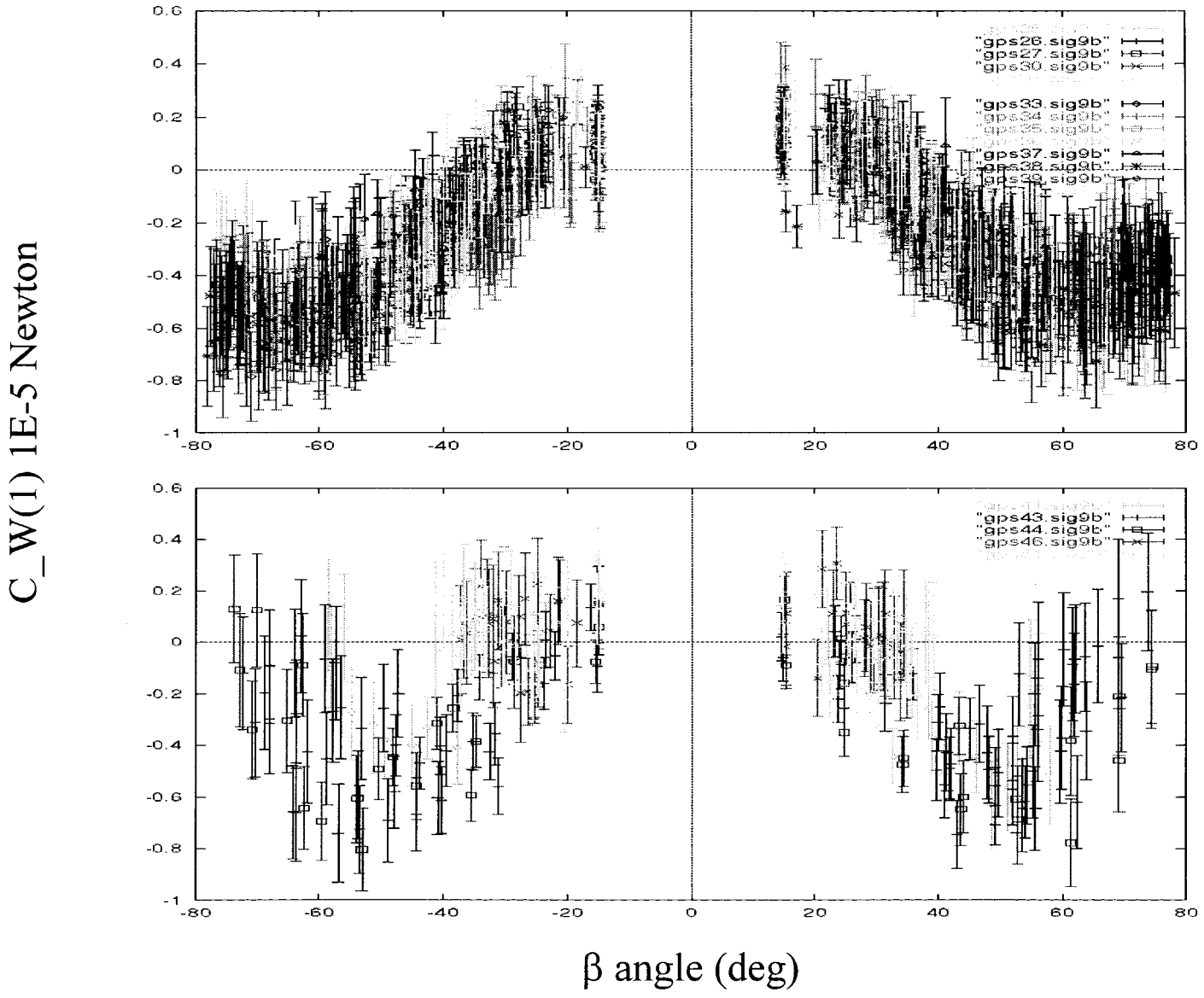
The Main Radiation Term



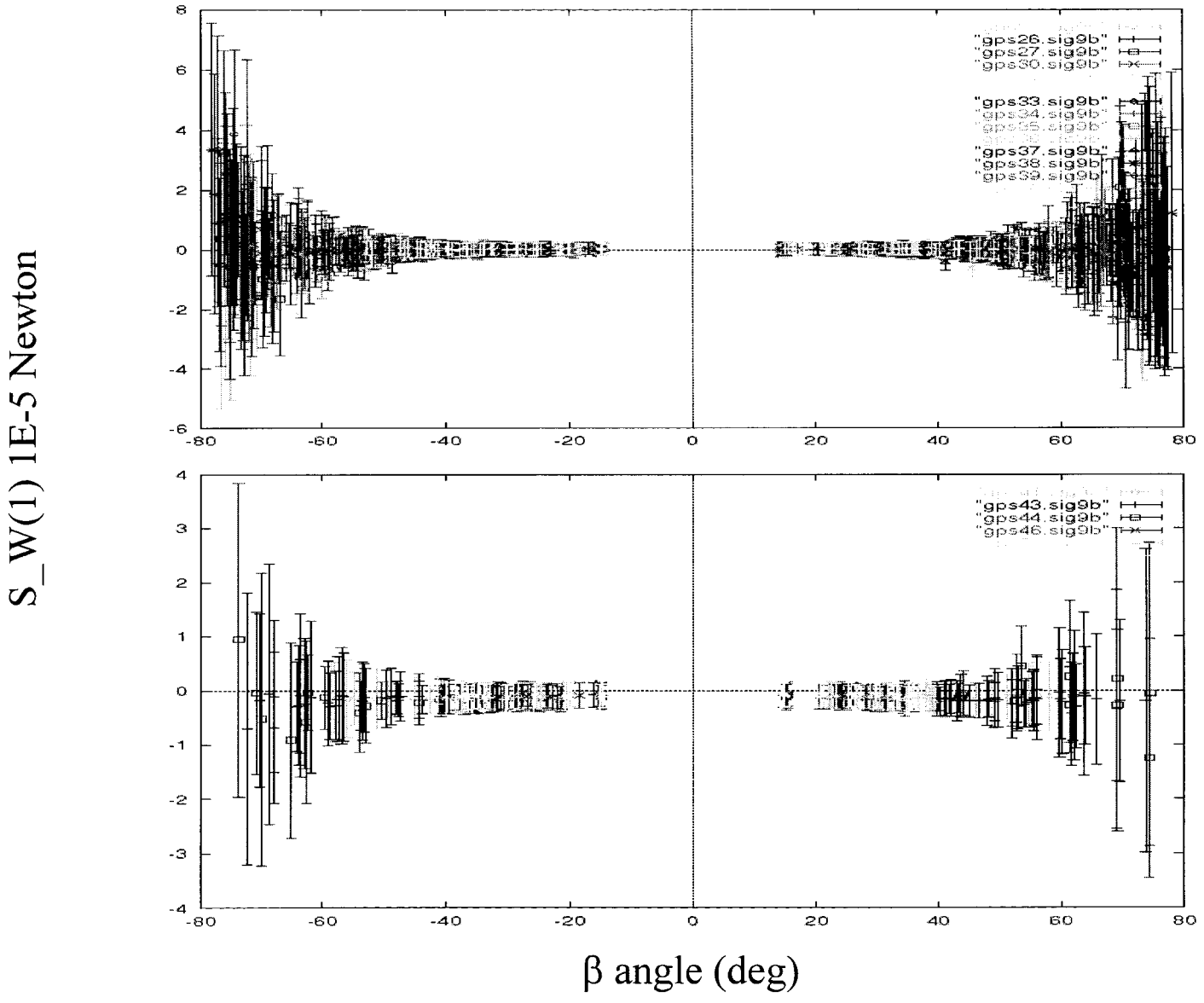
Model Parameter C_V(1)



Model Parameter C_W(1)



Model Parameter S_W(1)

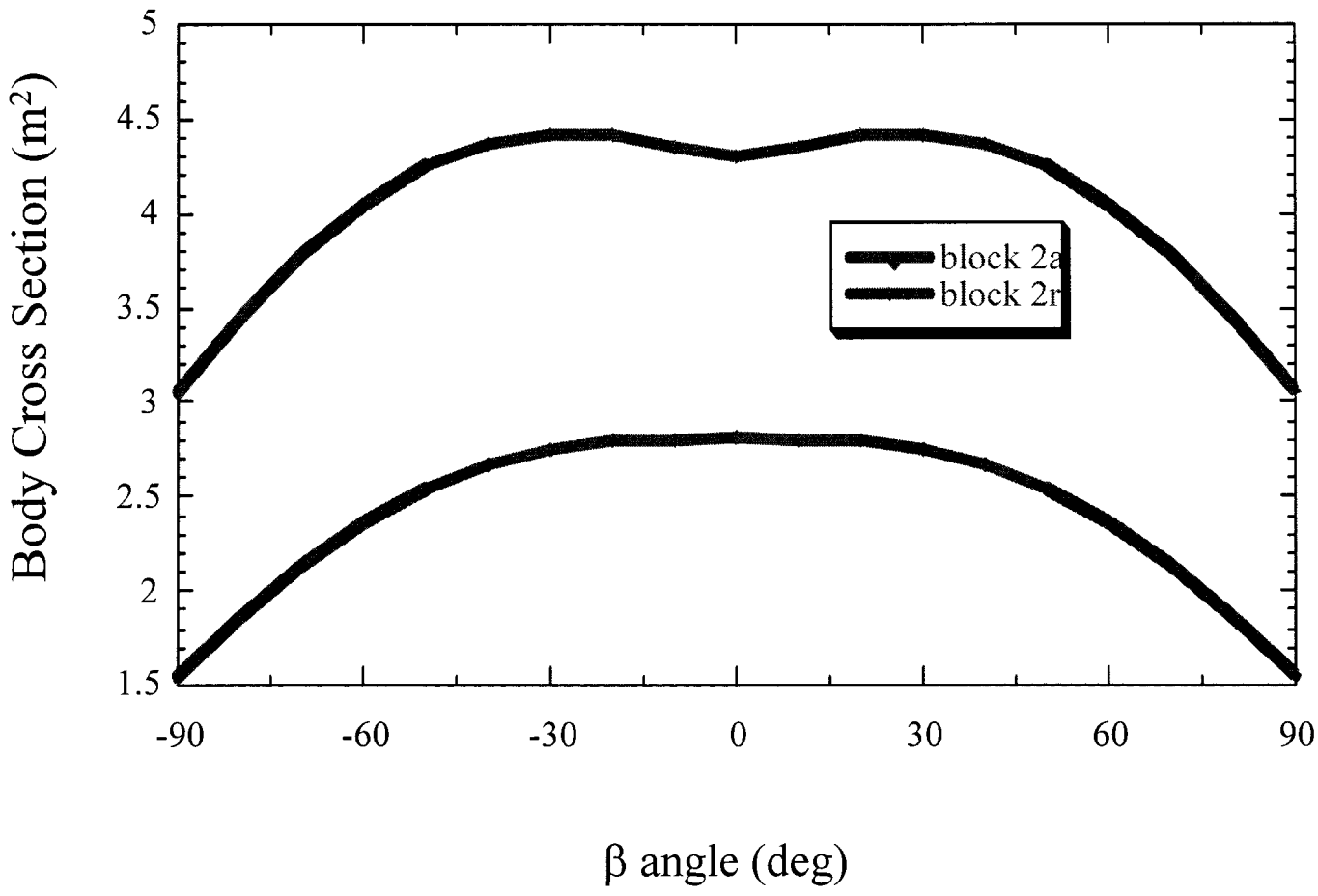


Characteristics of Model Parameters

- Dependency on β angle
  - Sampling effect of orbit arc
  - Mismodeling in satellite attitude

- Larger uncertainty at high β angle
  - Samll variation of ε at high β angle region
  - High correlation between base functions of Fourier expansion

Orbit Arc Sampling Effect

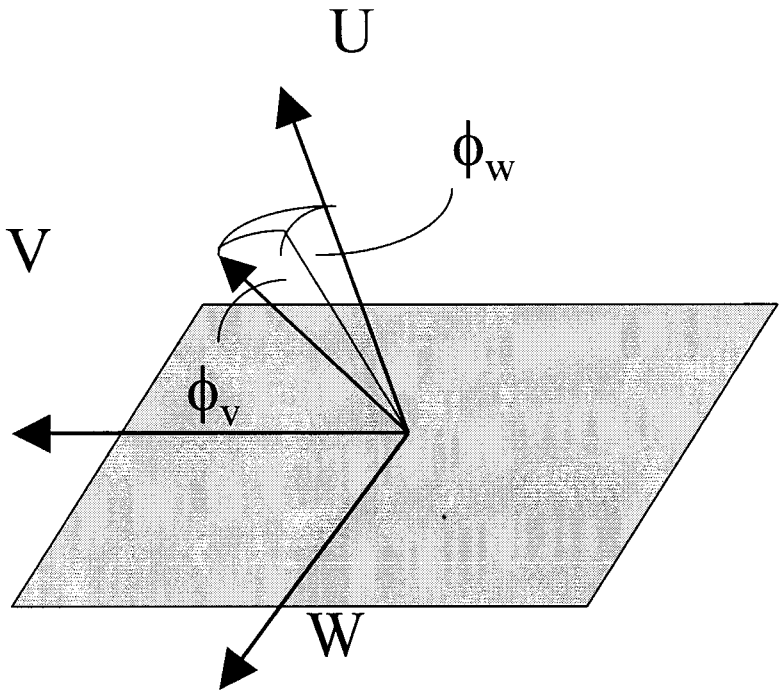


Dynamic Effect of Solar Panel Mispointing

For small mispointing angle
ϕ_v, ϕ_w

$$F_v = \frac{2}{3} PA\nu(1+2\mu)\phi_v$$

$$F_w = \frac{2}{3} PA\nu(1+2\mu)\phi_w$$



For Block IIA satellite:

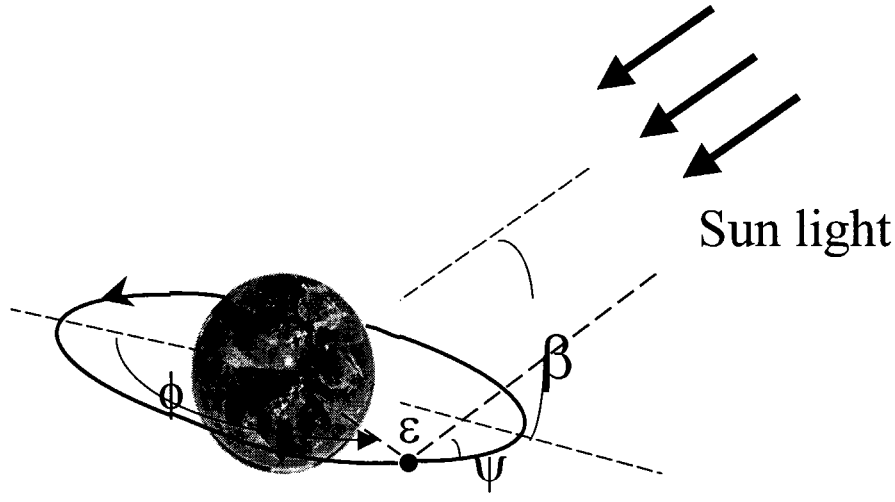
$(2/3)\ P\ A\ \nu\ (1+2\mu)$
$= 0.407\ 10^{-9}$ m/sec^2/deg

GPS Satellite Attitude Change Rate

$$\cos\varepsilon = \cos\beta\cos\phi$$

Yaw rate projected to V direction:

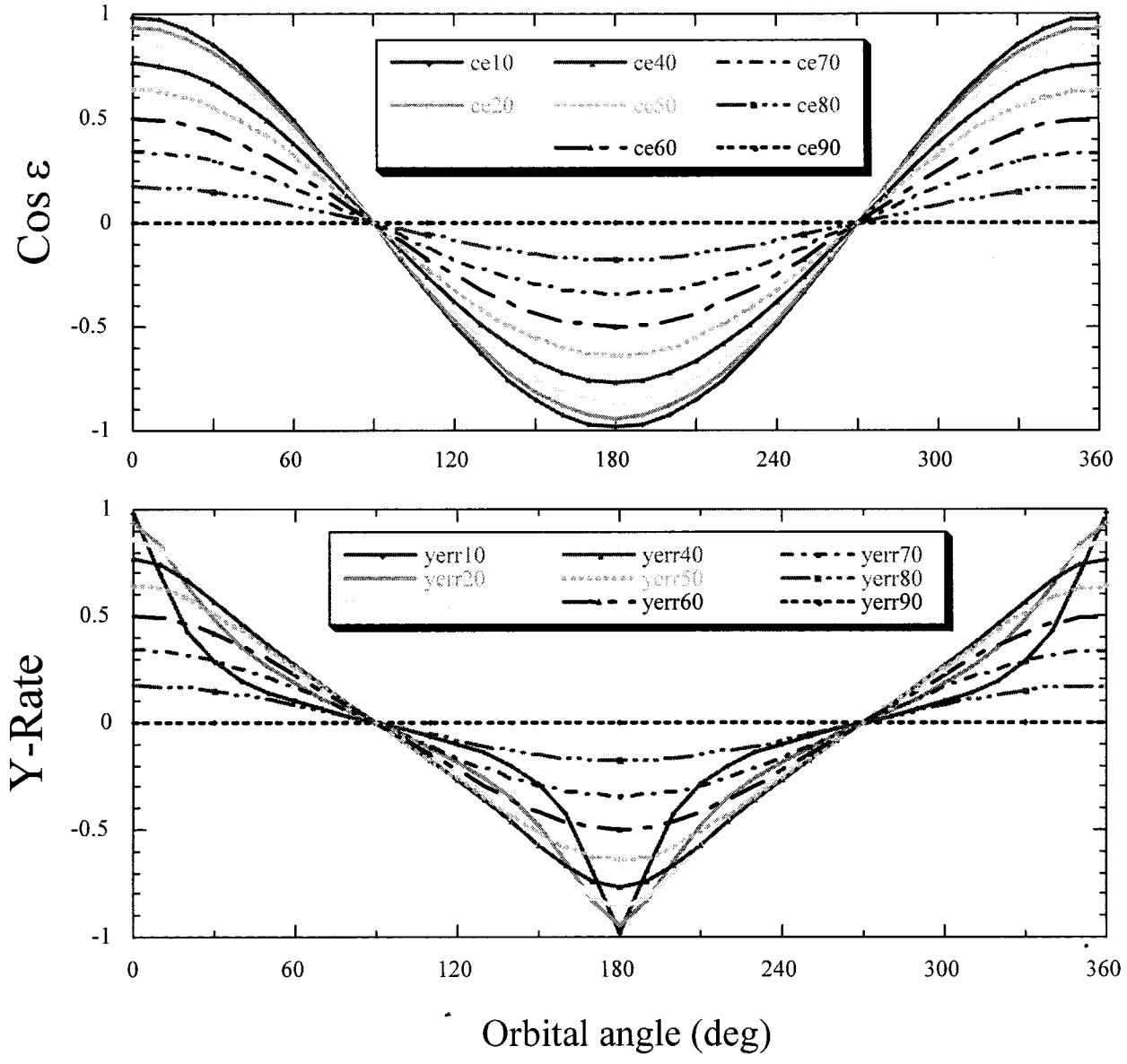
$$\dot{\psi}\sin\varepsilon = \frac{\sin\beta\cos\varepsilon}{\sin\varepsilon}\dot{\phi}$$



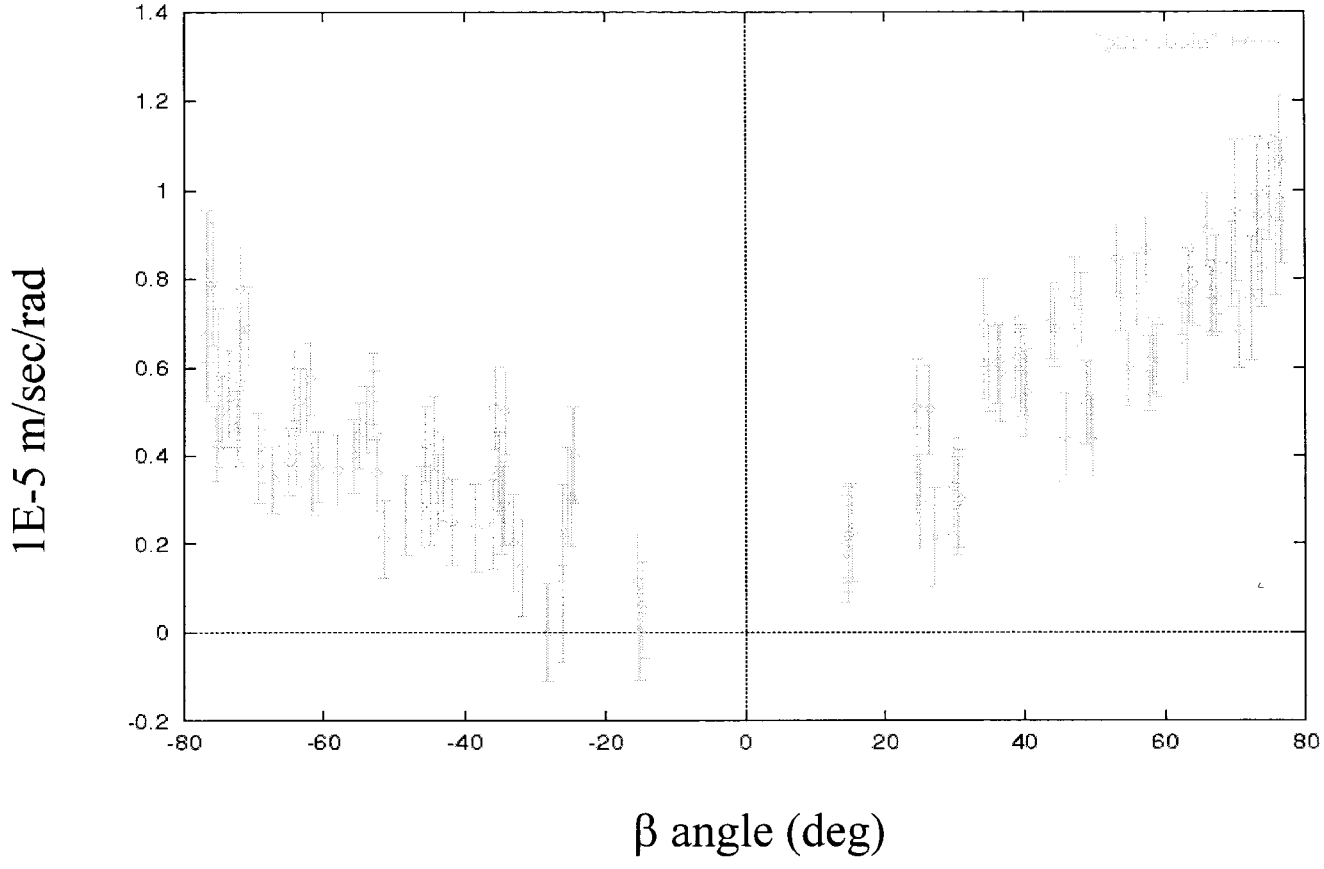
Pitch rate:

$$\cos\psi\,\dot{\phi} = -\frac{\cos\beta\sin\phi}{\sin\varepsilon}\dot{\phi}$$

Base Functions in Modeling

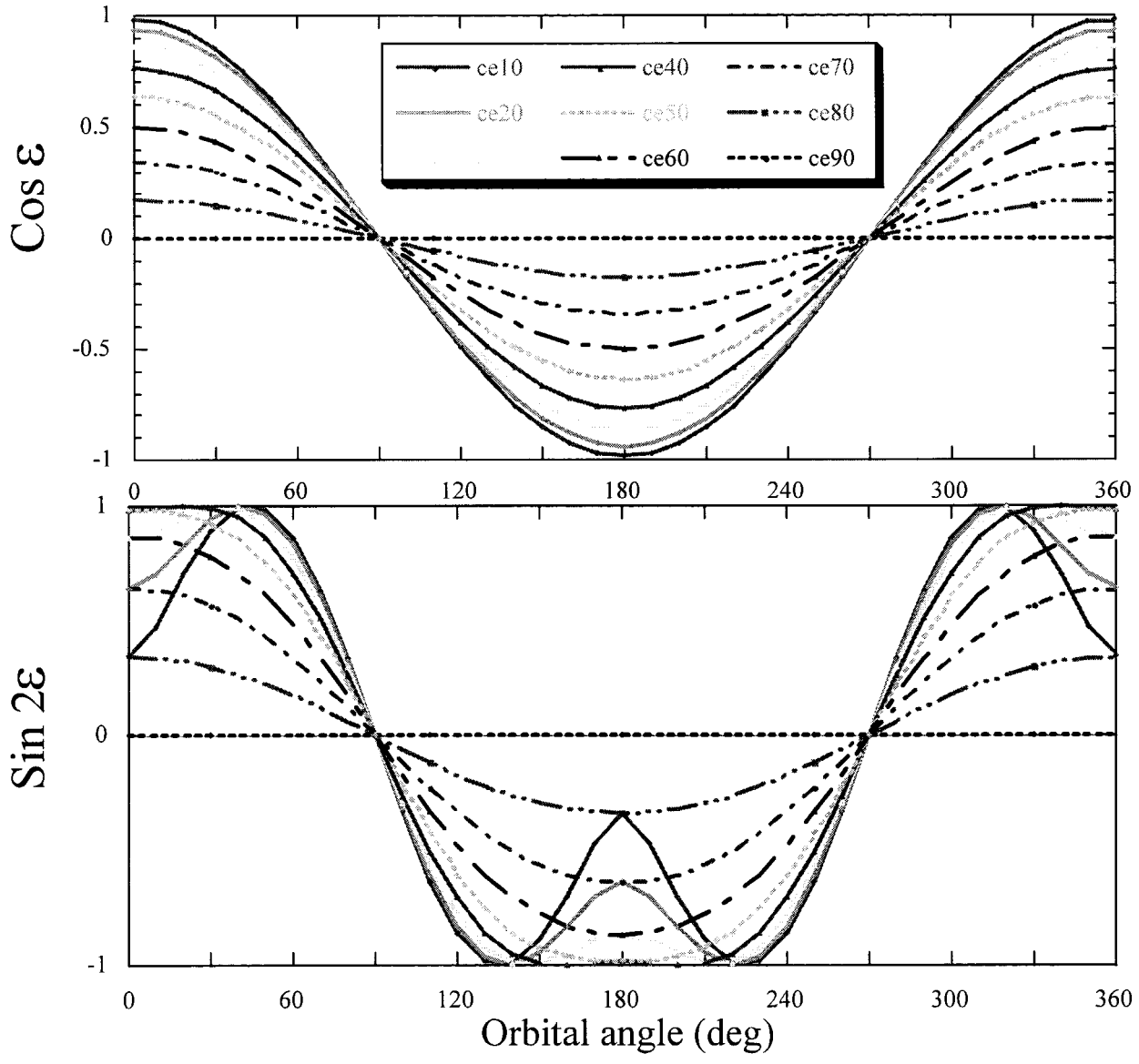


Estimated Yaw-Lag Coefficient for GPS25

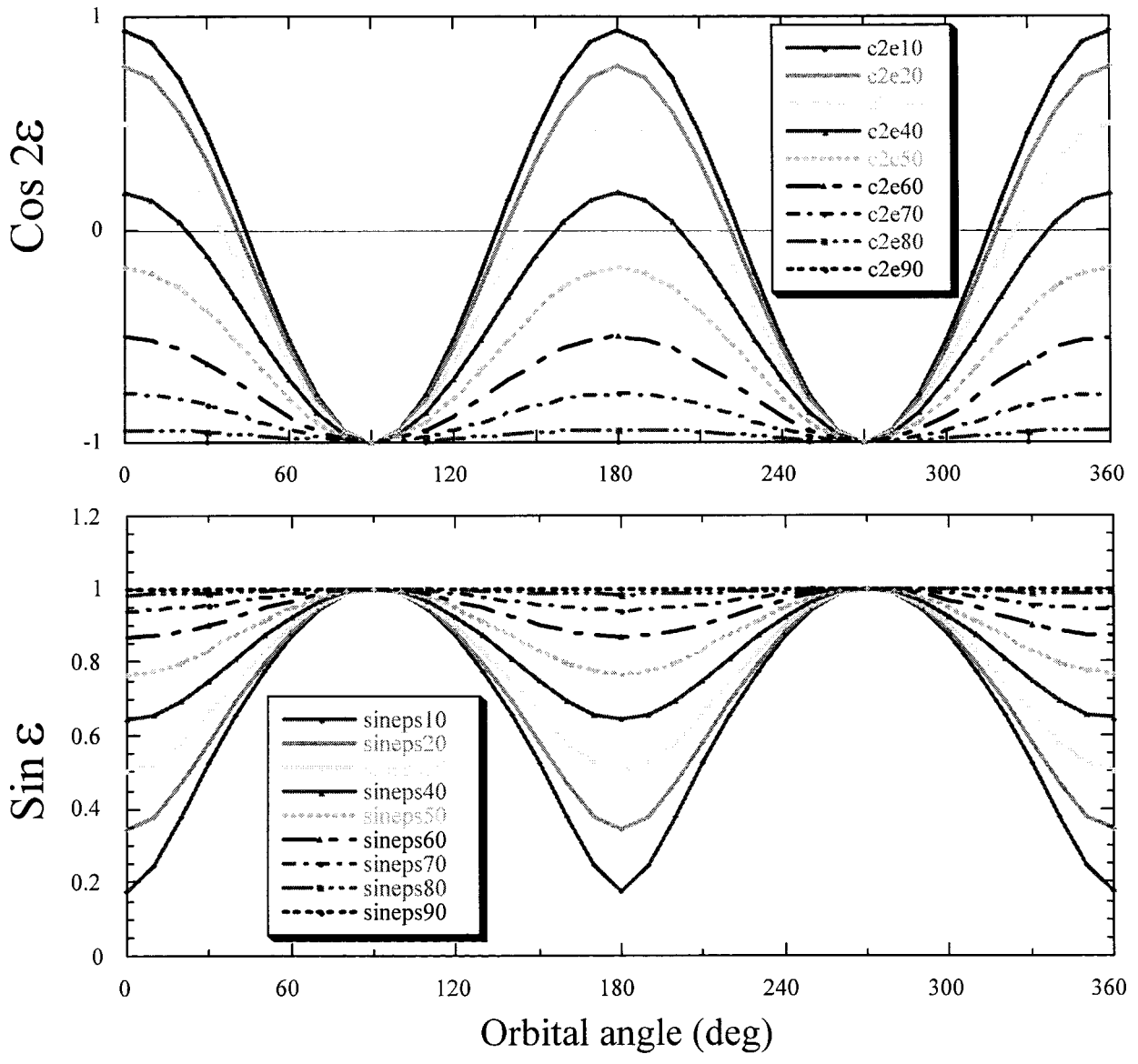


Converted average lag is about 3 minutes

Base Functions as Function of β and ϕ



Base Functions in Fourier Expansion



Summary

--New SRP model derived from larger orbit data set improves both orbit fit and prediction, especially for Block IIR satellites

--Model parameters show significant β angle dependency, there is a possible satellite yaw attitude lag

--Some model parameters are highly correlated at high β angle region, physical modeling (e.g., box-and-wing) should be investigated in the future